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THE EFFECTS OF DISPLACED EARS ON AUDITORY LOCALIZATION

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ABSTRACT

The techniques of rearrangement and disarrangement have been used to alter the normal relationship between an observer and his auditory or visual environment. In general, rearrangement leads to orderly adaptation of perceptual-motor performance, while disarrangement leads to degradation of performance.

This experiment was an auditory rearrangement. Subjects' judgments of auditory direction were displaced laterally by means of a high-fidelity pseudophone that effectively rotated the interaural axis through a 20 degree horizontal angle. After exposure sessions that consisted of walking repeatedly toward a fixed sound source for 20 minutes, two of the four experimental subjects demonstrated significant shifts averaging 6 degrees in their judgments of auditory direction. The shifts partially compensated for the error of localization produced by the pseudophone.

The shifts in localization are discussed in terms of the nature of the exposure situation and the factors that are likely to be responsible for compensation.

I. INTRODUCTION

One way to study the relationship between the percipient human observer and his external world is to alter that relationship and observe the consequent changes in perception and behavior. Such alterations may be produced by interposing appropriate devices between the observer and his sense stimulating environment. Because both vision and audition utilize environmental cues to guide spatially oriented behavior, they are particularly suited to this type of experiment.

A. Rearrangement and disarrangement.

Atypical stimulus situations may be classified in many ways. Psychologists since Helmholtz (1924-1925) have described adaptations to perceptual alterations created by inverting, reversing, or otherwise distorting the visual field. Held and Freedman (1963) have offered an explanation for these adaptations inferred from demonstrations that the perceptual changes which occur are contingent upon the conditions of movement during atypical exposure. Sensory feedback dependent upon self-induced motor activity of the observer, called reafference by von Holst (1954), is required for any large perceptual alteration to occur.

The visual experiments of Helmholtz (1924-1925), Stratton (1897), Ivo Kohler (1953), Smith and Smith (1962), Taylor (1962), and Held before 1960 fall into the category designated as rearrangement. "A rearrangement, such as is effected either by wedge prisms before the eyes, or by pseudophones, transforms the relation between motor output and sensory feedback in an isomorphic, continuous, and time independent manner" (Held & Freedman, 1963). For example, wedge prisms displace the visual field with respect to the eye, but the relations of the parts within the field are preserved, and a one-to-one relationship between movement and contingent changes in feedback stimulation may still be specified. Adaptation to this kind of change would take the form of a compensatory shift in movements.

Disarrangement, on the other hand, may be effected by introducing a time-varying factor into the feedback loop; there results a decorrelation between movement and the resulting sensory changes, a

decorrelation between efferent (motor) and reafferent signals. This decorrelation leads to increasing ambiguity in the efferent-reafferent relationships with consequent degradation of performance.

B. Previous auditory studies.

A number of auditory rearrangement experiments have been reported. In 1928 Young used a pseudophone to produce right-left reversal of localization. His device consisted of a receiving trumpet on either side of the head connected by rubber tubing to the opposite ear. Several days of exposure in the normal environment did not produce any correction of the reversal or any aftereffect when the pseudophone was removed. Visible sound sources did not seem to be dissociated from their auditory locations. Willey, Inglis, and Pierce (1937) using similar equipment concluded that prolonged exposure to the reversal did not lead to reorganization of the auditory-visual relationship, but that the auditory cues for the location of seen objects did seem to be repressed.

Held (1955) rotated the observer's effective interaural axis 22°. After 60 min. of exposure during which the observer walked in relation to fixed sound sources, corrective shifts of up to 10° in his apparent auditory mid-line were measured. Although a variety of apparently comparable experimental conditions were used, the only effective ones were those in which the observer walked directly toward or away from the sound sources. There were no controls for passive movement, or for restricted movement, with equivalent stimulation.

Freedman has reported a series of auditory disarrangement experiments (Freedman & Pfaff, 1961, 1962; Freedman & Secunda, 1962;

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Freedman & Zacks, 1964) demonstrating the importance of sensory-motor interaction in the deterioration of dichotic time difference discrimination which is basic to auditory localization. Under various movement conditions, observers were exposed to continuous white noise generated by separate, equivalent sources supplying the two ears through earphones. Normally, there are unique relationships between interaural time, phase, and intensity differences on the one hand and positions or movements of the observer on the other. Listening to any sound through earphones destroys these systematic relationships. Furthermore, active movement of an observer while listening to dichotic white noise would result in many interaural differences occurring simultaneously with any particular movement instead of the normally correlated changes. Efferent-reafferent relationships should become less precise with more variable perceptual performance as a consequence.

C. The present experiment.

This experiment involved auditory rearrangement. Subjects' interaural axes were rotated through fixed and constant angular distances; they were then exposed to a fixed sound source, and the resultant shifts in auditory localization were measured. The method differs from that of Held (1955) in its closer approximation to natural stimulus conditions: artificial pinnae were attached to the microphones of a high-fidelity pseudophone, and exposure took place in an ordinary experimental room rather than in an anechoic chamber.

Our aim was not primarily to isolate the critical factors in this type of adaptation, but to develop the technique for use in further studies of sensorimotor plasticity and intersensory phenomena.

II. THE EXPERIMENT

A. Hypothesis.

Subjects whose judgments of auditory direction are displaced laterally by a pseudophone will demonstrate compensatory shifts of localization after walking directly toward a fixed sound source for an extended period of time. The auditory median plane will shift in the direction of the constant error produced by the pseudophone. Measured as an aftereffect with the pseudophone undisplaced, the shift will cause an error opposite the direction of the original displacement.

B. Equipment

Figure 1 shows the components of the sound system. Bruel and Kjaer condenser microphones (Type 4133) with cathode followers (Type 2615) and microphone power supplies (Type 2801) were connected across 500-ohm Borg Micropot potentiometers with digital dials to the two-channel amplifier (United Research, Inc., Driver LH-3). The amplifier drove a pair of condenser earphones (United Research, Inc.).

Insert Figure 1 about here

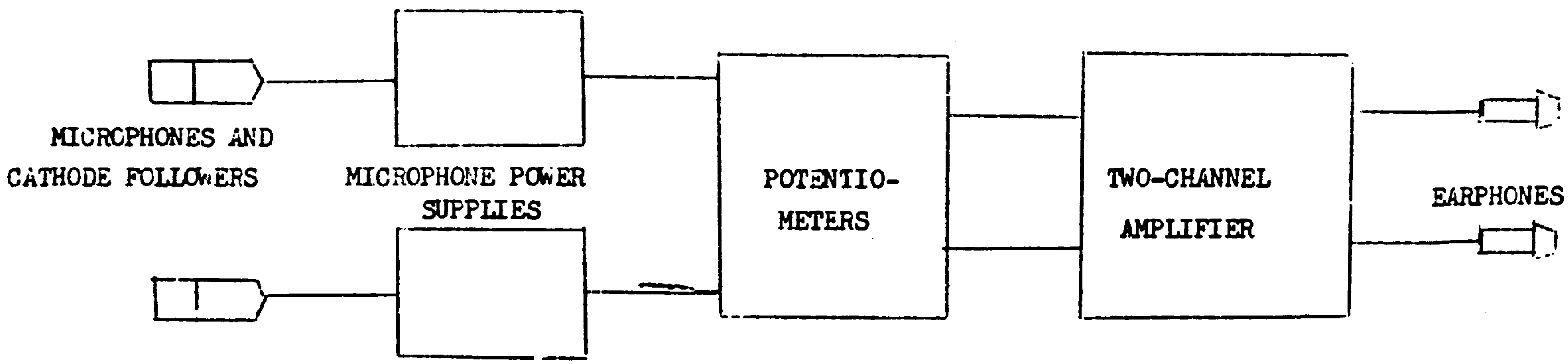

FIGURE 1. COMPONENTS OF THE SOUND SYSTEM,

The microphones were mounted in artificial pinnae on the ends of a 10 1/4 inch rod which could rotate on a small circular platform and be fixed in any position. A scale on the base of the platform was marked at 5 degree intervals to 45 degrees on each side of a point to be aligned with the median plane of the subject's head. The platform was bolted to a steel plate curved to fit the head. A cushion was taped to the bottom of this headplate. The headband of a pair of sound-attenuating earmuffs (Noisefoe Mark II Ear Protectors, Mine Safety Appliances, Co., No. HB-8221-1) fit between the circular platform and the headplate. With the platform and headplate bolted together the headband was held firmly in position. Figure 2 shows details of this construction. Figure 3 shows a subject wearing the pseudophone in its normal and displaced positions.

Insert Figures 2 and 3 about here

The earphones were held in position with modeling clay shaped to fit the subject's pinnae.

The entire experiment was conducted in a room about 13 1/2 feet by 7 feet. All four walls and the ceiling were of acoustic tile. The localization test scale extended across one of the end walls, about five feet from the floor.

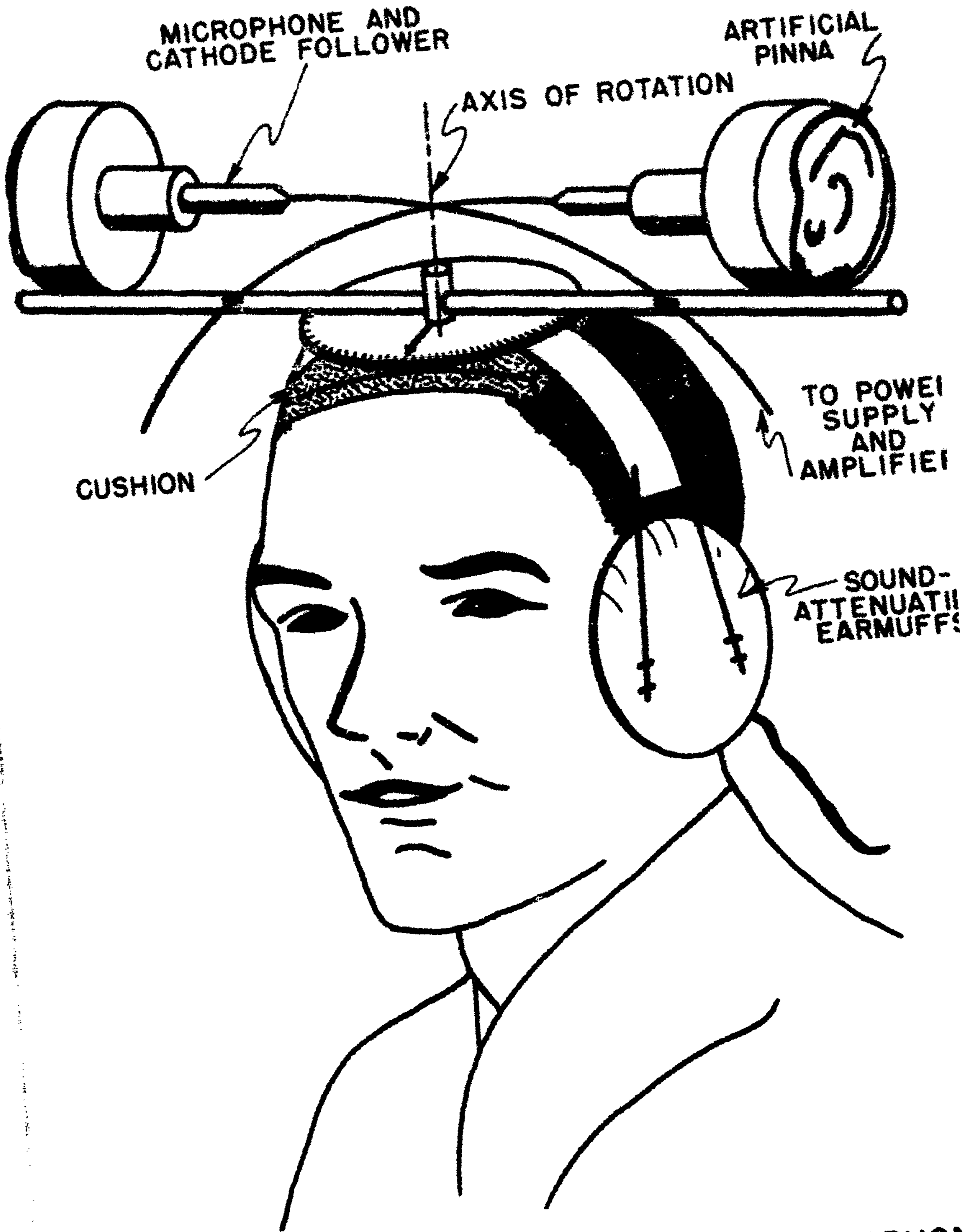

FIGURE 2. CONSTRUCTION OF THE PSEUDOPHONE.

a. Normal axis position.

b. Interaural axis rotated 20°.

SUBJECT WEARING THE PSEUDOPHONE

The localization test scale formed a 60 degree arc of a circle with a radius of 81 inches. It was numbered at 3 degree intervals and marked at 1 1/2 degree intervals. During the test procedure the subject sat in a rotating chair at the center of the circle. A buzz composed of an 0.01 ms pulse every 6.3 ms was the test stimulus (about 160 pulses per second). It was produced by a Tektronix 162 Waveform Generator and presented through a Permoflux PDR-8 earphone, which could be placed behind any of the numbered positions on the scale. A pushbutton operated by the subject sounded the stimulus continuously as long as the button was depressed.

C. Subjects and training.

The subjects were four male Harvard and Tufts undergraduates with no known hearing defects. Their ages ranged from 17 to 20 years.

Each was given a series of preliminary tests of localization without the pseudophone. The criterion for initial acceptance was a standard deviation of ± 3 degrees or less on two of the last three tests given without corrective feedback.

Each subject also had one or two series of training tests with the pseudophone, undisplaced and displaced to the left and right. Each consistently performed with a standard deviation of ± 4.5 degrees or less and a mean error between 15 and 25 degrees when the pseudophone was displaced 20 degrees.

D. Instructions and test procedure.

Instructions for the test during the experimental session were uniform in directing the subject to turn his head and body to face the

stimulus before opening his eyes. Judgments were given to the nearest half-unit (1 1/2 degrees). Stimuli were selected alternately from the left and right sides of the scale within a range of 15 degrees from the center. The subject sat facing the center before each presentation of the stimulus. A complete test consisted of ten consecutive judgments, for which the mean and standard deviation of the errors were calculated.

E. Exposure session.

Each subject had two exposure sessions on different days, once with the left ear leading by 20° and once with the right ear leading by 20°.

The following sequence was used for each exposure session:

1. Balancing intensity: With the microphone platform mounted separately so the stimulus speaker was equidistant from the two microphones, the subject listened through the earphones and balanced the intensities of the two sides by adjusting the potentiometer dials until the sound appeared to be centered. The average of six successive adjustments was then set on the dials for the remainder of the session.

2. Pre-test: Wearing the pseudophone with the interaural axis in its normal position, the subject took the localization test.

3. Exposure: The room was darkened except for two tiny lights on the end walls; the speaker was concealed at one end directly beneath one of the lights. Tektronix 162 Waveform Generators produced the stimulus buzz continuously for the first four seconds of every ten second period. With the pseudophone axis displaced 20 degrees to the left or

right, the subject was instructed to walk a straight path between the two lights, going toward the stimulus while it was sounding and returning when it was silent. He was to keep his head facing forward while approaching the stimulus and not to turn until the sound had stopped. At the end of the return trip he was to turn and be ready to begin the next approach before the stimulus had started. In this way the only motion made while the stimulus sounded was directly toward it. This procedure was continued for 20 minutes.

4. Post-test: At the end of the exposure period the lights were turned on and the subject had another localization test with the pseudophone axis in the normal position.

F. Computation.

The difference between the mean error of the pre-test and that of the post-test was taken as a measure of the shift in localization produced by the exposure condition.

III. EXPERIMENTAL RESULTS

Table 1 shows the amount of shift in degrees and the standard deviations of pre-test and post-test for each of the eight experimental sessions. Plus (+) indicates shifts to the right; minus (-) indicates shifts to the left.

Insert Table 1 about here

1/2 FRAMES

Table 1

SHIFTS OF LOCALIZATION AFTER 20 MINUTES EXPOSURE
WITH 20 DEGREE PSEUDOPHONE DISPLACEMENT

	Left Ear Leading			Right Ear Leading		
		Standard Deviation			Standard Deviation	
Subject	Shift	Pre-test	Post-test	Shift	Pre-test	Post-test
FE	+ 3.9°	± 2.3°	± 2.7°	- 9.6°	± 4.2°	± 4.2°
MH	+ 5.9°	± 3.3°	± 3.6°	- 4.8°	± 2.4°	± 4.5°
IMH	- 1.8°	± 2.7°	± 2.9°	- 2.1°	± 2.6°	± 3.9°
JMB	+ 0.2°	± 3.2°	± 2.8°	- 1.5°	± 3.6°	± 4.2°

4

Two of the four subjects (FE and MH) shifted significantly in each condition. With the other two subjects (IMH and JMB) shifts were smaller than the individual standard deviations and no larger than shifts sometimes observed between two consecutive tests in training.

The Wilcoxon Matched-pairs Signed-ranks Test (one-tailed) was used to estimate the significance level of these shifts. For subjects FE and MH *p* was $<$ 0.C25 for every condition. These probability values are shown in Table 2.

Insert Table 2 about here

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Table 2

SIGNIFICANCE OF SHIFTS

Subject	Exposure Condition[a]	Amount of shift	Probability of rejection[b]
FE	A	+ 3.9°	$p < 0.025$
	B	- 9.6°	$p < 0.005$
MH	A	+ 5.9°	$p < 0.01$
	B	- 4.8°	$p < 0.005$

[a] A = left ear leading; B = right ear leading

[b] Wilcoxon Matched-pairs Signed-ranks test, one tailed

IV. DISCUSSION

A. Nature of the exposure condition.

Rotation of the interaural axis with a pseudophone produces a lateral error in auditory localization toward the side of the leading ear and equal to the angle of rotation. Figure 4 shows how this rearrangement affects localization judgments. The broken lines are S's normal interaural axis and median plane, while the solid lines are the interaural axis and auditory median plane determined by the pseudophone. Normally the auditory median plane and perceived "straight ahead" coincide; a sound source that produces no interaural time and intensity differences is correctly localized in the median plane of the head. With a displacing pseudophone, however, a sound source which produces no interaural differences is not in the median plane of the head. In Figure 4 the pseudophone is rotated 20 degrees counterclockwise, shifting the auditory median plane 20 degrees to the left. As a result, sounds are perceived 20 degrees to the right of their actual positions. For example, a sound source at A, in the auditory median plane, is heard at B, in the median plane of the head. Similarly, a sound source at B is heard 20 degrees to its right, at C.

Insert Figure 4 about here

The experimental exposure condition involved walking straight toward a sound source in the median plane of the head. This situation is shown in Figure 2. When S is at position (1), the apparent position of a sound source at A is displaced to B_1. As S moves to position (2),

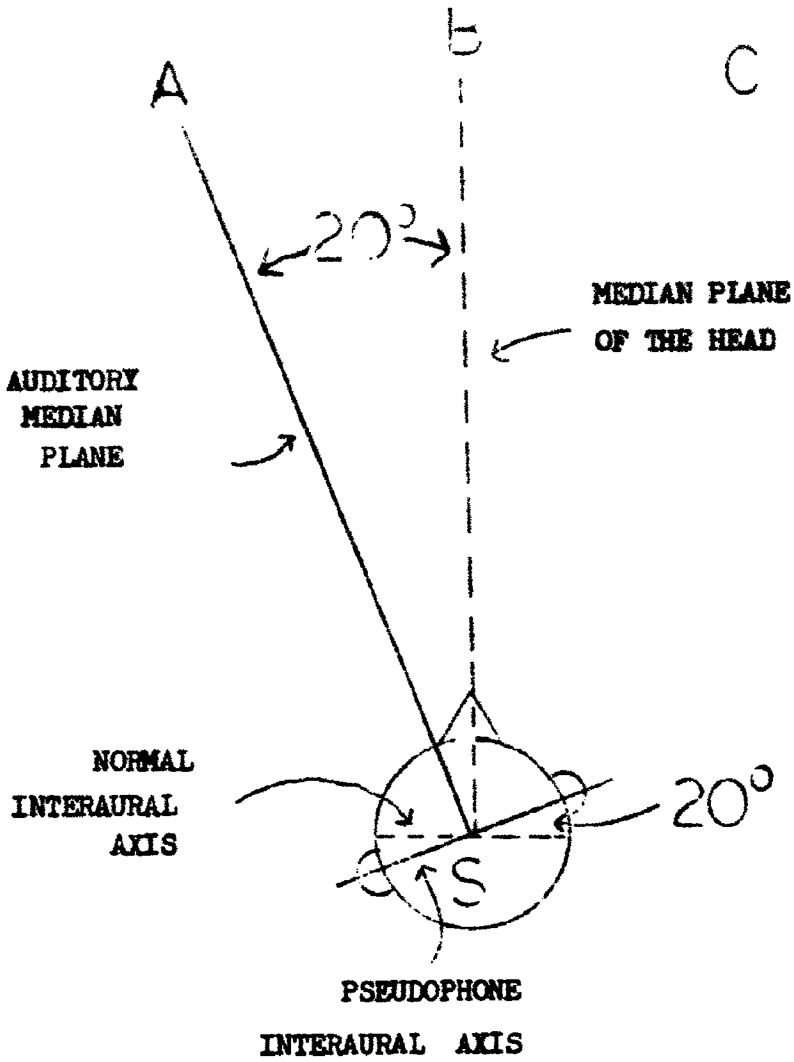

FIGURE 4. PSEUDOPHONIC DISPLACEMENT OF AUDITORY LOCALIZATION.

the angular displacement remains constant, but as the distance between S and A decreases, this angle intercepts a shorter arc, shifting the apparent position to B_2. Figure 6 shows that the interaural time difference remains approximately constant as S approaches A. The lines P_L and P_R are the paths of sound from A to the left and right ears of the pseudophone. The difference between the lengths of the two paths is responsible for the interaural time difference, and this path difference remains nearly constant as S walks toward A.

Insert Figures 5 and 6 about here

What appeared to happen after exposure is that sound sources producing some range of time differences between zero and the constant time difference present during exposure were judged straight ahead. This partially compensated for the error caused by the pseudophone. Prolonged exposure might lead to complete compensation: the sound source which is straight ahead would be judged straight ahead despite the displacement of the pseudophone. When the pseudophone was returned to the normal position, the time difference which was perceived as straight ahead came from sound sources located on the side opposite the direction in which sounds were originally displaced by the pseudophone. This was measured as the aftereffect.

Interaural intensity differences were probably less important than time differences. Since intensity differences are an irregular function of azimuth and frequency, they are not a precise cue for localization (Nordlund, 1962). In addition, the intensity difference varies with

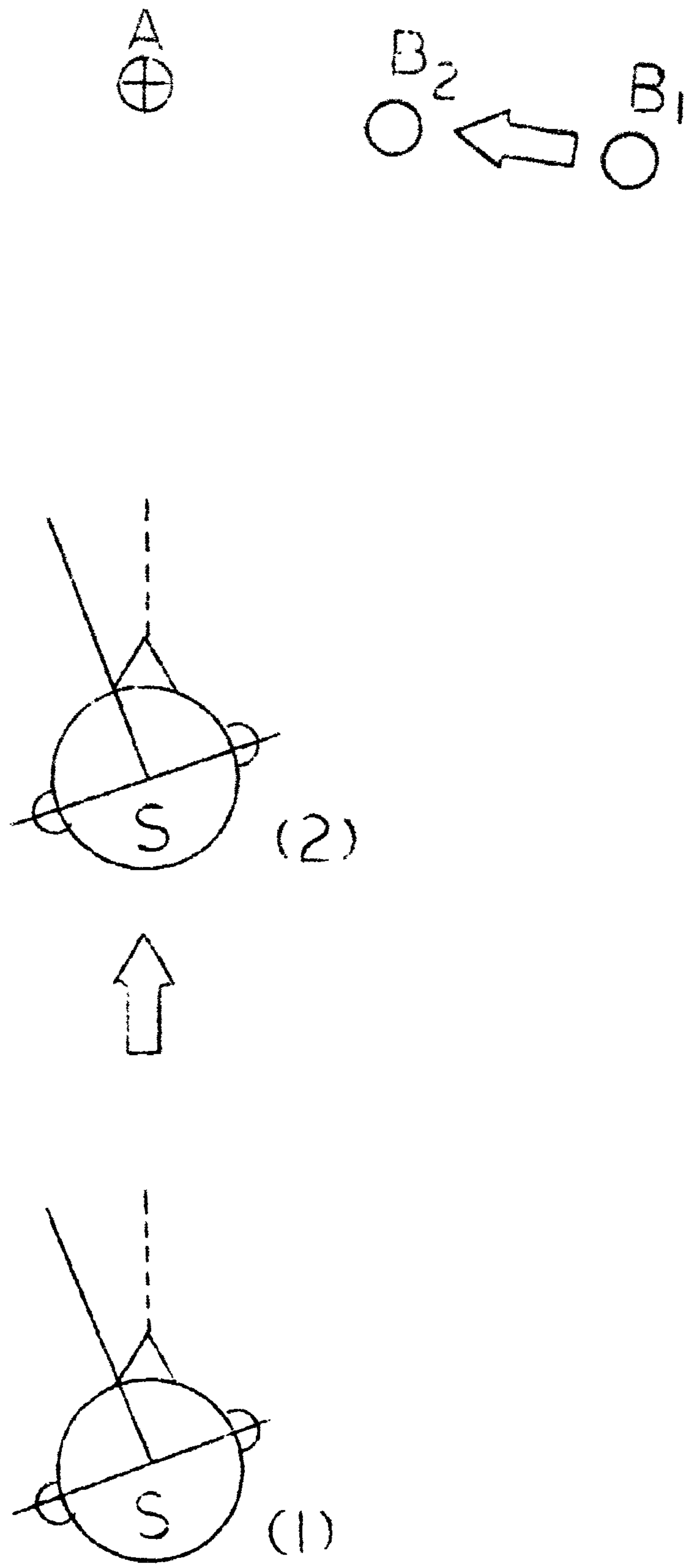

FIGURE 5. APPARENT CHANGE OF POSITION OF SOUND SOURCE (A) AS S WALKS STRAIGHT TOWARD IT.

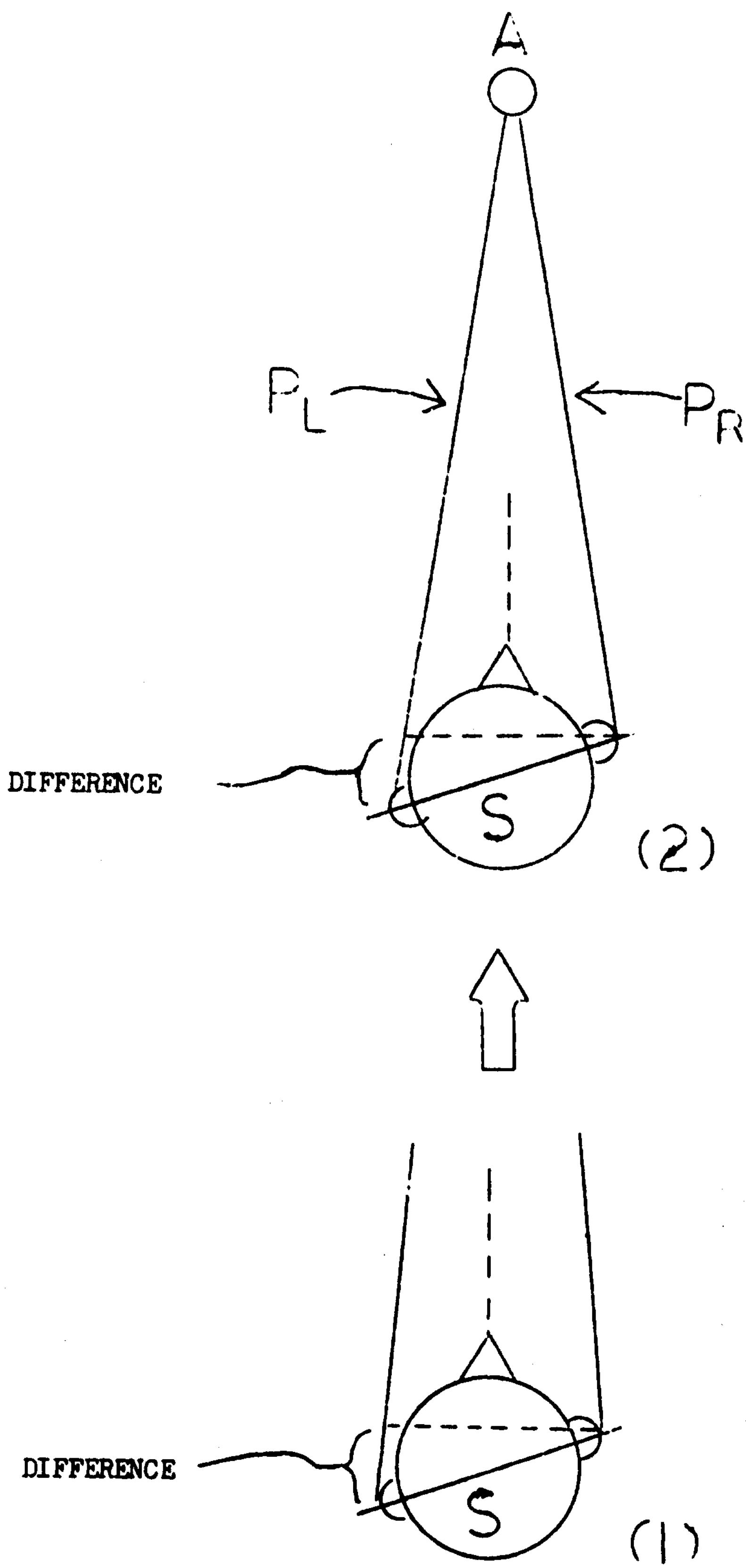

FIGURE 6., CONSTANCY OF INTERAURAL TIME DIFFERENCE AS S WALKS STRAIGHT TOWARD SOUND SOURCE (A).

distance from the sound source, so that in the experimental exposure condition there was no relatively constant intensity difference accompanying the subject's motion.

B. Conditions necessary for producing shifts of localization.

Under normal conditions walking straight ahead in the presence of a sound source is accompanied by a constant interaural time difference only when the source is in the median planes of the head and body. In this case the constant time difference is no difference at all: i.e., zero. In the experimental exposure condition walking straight ahead was accompanied by a constant time difference not equal to zero.

Held (1955) concluded that shifts in localization required both the constant time difference and the subject's walking toward the sound source. It is possible, however, that some or all of the observed shift in localization may be due to exposure to the constant time difference, regardless of the subject's state of motion. In all the rearrangement and disarrangement experiments discussed by Held and Freedman (1963), active motion by the subject was shown or justifiably assumed to be necessary for compensation and degradation to occur. It would seem likely that for auditory rearrarrangement to be effective, the subject's motion is essential. This hypothesis can be tested easily. If the subject were to wear the displacing pseudophone and sit facing the sound source instead of walking toward it, he would be exposed to approximately the same constant time difference as in the active condition. Whether or not shifts in localization occur in this condition, the results will further define the nature of compensation for auditory rearrangement.

C. Summary and conclusions.

Shifts in auditory localization were demonstrated which partially compensated for a pseudophonic displacement of the ears. With a 20 degree displacement of the auditory median plane, shifts up to 9.6 degrees were measured after 20 minutes of exposure that consisted of walking repeatedly toward a fixed sound source. However, significant shifts (averaging 6 degrees) were measured with only two of the four experimental subjects.

The magnitude of the shifts is about the same as those that Held (1955) measured after 20 minutes of continuous exposure. Here the actual exposure to the sound source was intermittent, totalling 8 of the 20 minutes. It is possible that with longer or continuous exposure all subjects would have shifted, and that with sufficiently long or periodically repeated sessions full compensation might have been achieved.

REFERENCES

Freedman, S. J. & Pfaff, D. W. The effect of exposure to dichotic noise on the discrimination of dichotic time differences. U. S. Air Force Office of Scientific Research, Tech. Rep. AFOSR-503, April, 1961.

Freedman, S. J. & Pfaff, D. W. The effect of dichotic noise on auditory localization. J. Audit. Res., 1962, 2, 302-306.

Freedman, S. J. & Secunda, S. An analysis of the effects of motion upon auditory function during prolonged atypical stimulation. U. S. Air Force Technical Report AFOSR-2078, Tufts University, Medford, Mass., April, 1962.

Freedman, S. J. & Zacks, J. L. Effects of active and passive movement upon auditory function during prolonged atypical stimulation. Percept. mot. Skills, 1964, 18, 361-366.

Held, R. Shifts in binaural localization after prolonged exposure to atypical combinations of stimuli. Amer. J. Psychol., 1955, 68, 526-548.

Held, R. & Freedman, S. J. Plasticity in human sensori-motor control. Science, 1963, 142, 455-462.

Helmholtz, J. V. Treatise on physiological optics. Vol. III. Rochester, N. Y.: Optical Society of America, 1924-1925.

Holst, E. V. Relations between the central nervous system and the peripheral organs. Brit. J. Animal Behav., 1954, 2, 89-94.

Kohler, I. Rehabituation in perception. Die Pyramide, 1953, 3(5-7).

Nordlund, B. Angular localization. Acta oto-laryngol., 1962, 55, 405

Smith, K. U. & Smith, W. M. Perception and motion. Philadelphia: Saunders, 1962.

Stratton, G. Vision without inversion of the retinal image. Psychol. Rev., 1897, 4, 341-360, 463-481.

Taylor, J. G. The behavioral basis of perception. New Haven: Yale Univer. Press, 1962.

Willey, C. T., Inglis, E. & Pearce, C. H. Reversal of auditory localization. J. Exp. Psychol., 1937, 20, 114-130.

Young, P. T. Auditory localization with acoustical transposition of the ears. J. Exp. Psychol., 1928, 11, 399-429.

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